Palaeogeography, Palaeoclimatology, Palaeoecology 512 (2018) 1–5

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Cenozoic climate change in eastern Asia: Part II

ARTICLE INFO

Keywords:
Geochemistry
Sedimentology
Clay mineralogy
Paleontology
Paleoanthropology
Complex societies

ABSTRACT

This special issue of *Palaeogeography Palaeoclimatology Palaeoecology* on "Cenozoic Climate Change in Eastern Asia" contains a series of multidisciplinary studies representing a wide range of research on paleovegetation, sedimentology, clay mineralogy, geochemistry, magnetostratigraphy, and climate modelling. The general significance of these studies is that analysis of terrestrial paleoclimate changes in eastern Asia may offer insights into the effects of Tibetan Plateau uplift, and ultimately the dynamic processes of global change that took hold throughout the Cenozoic. The present volume is Part II of this special issue. The first part of the special issue was dedicated to understanding eastern Asian paleoclimate variation during the Cenozoic by especially evaluating proxy data from geochemistry and climate modeling. Part II includes additional geochemical studies of terrestrial deposits from different regions of eastern Asia as well as climate modeling. Some of these papers focus on the impact or effect of these climatic changes on various floras and faunas in this region. In these studies, the period investigated ranges from the Eocene to the middle Holocene, thus encompassing most of the Cenozoic. Collectively, these studies provide significant new insights into the Cenozoic paleoclimate framework of eastern Asia.

1. Introduction

This is Part II of the special issue of *Palaeogeography, Palaeoclimatology, Palaeoecology* entitled "Cenozoic Climate Change in Eastern Asia". The first part of the special issue (*PPP* volume 510) was dedicated to understanding paleoclimatic variation during the Cenozoic by especially evaluating proxy data from geochemical and climate modeling studies (Hong et al., 2018). Part II continues in this direction by including a series of studies on the geochemistry of terrestrial deposits from different regions of eastern Asia, climate modeling, and the impact of climatic changes on the floras and faunas of this region.

2. Cenozoic climate change in East Asia

Paleosols record soil-forming climate variables such as precipitation, temperature, and atmospheric pCO_2 level during the period of soil formation, and as such, archive information about terrestrial paleoenvironmental and paleoclimatic variation at the time of formation (Sheldon and Tabor, 2009). Here, Song et al. (2018a) investigate the clay mineralogy and carbon and oxygen isotopic compositions of pedogenic carbonates in the Eocene fluvial sediments of the Lulehe Formation in the Qaidam Basin, a time period that covers the Early Eocene Climatic Optimum event (EECO, ~52–44 Ma). The paleosols predominantly consisted of pedogenic smectite and mixed-layer illite/smectite (I/S) minerals, suggesting a seasonal paleoclimate with warm-wet summers during the Early Eocene in the Qaidam Basin. The $\delta^{13}C$ values of the Lulehe Formation carbonate nodules that range from −5.0 to −9.5 ‰ (mean −7.1 ± 0.8 ‰) are notably higher when compared to modern C_3-plant-derived soil nodules (−9 to −13 ‰). This pattern reflects higher atmospheric pCO_2 prevailed during the Early Eocene as well as high temperatures during the EECO (Song et al., 2018a). The calculated $\delta^{18}O$ values for paleo-surface water composition from the Early Eocene are −7.9 ‰ to −5.0 ‰ (VSMOW), which are significantly higher (by 3.3 ± 1.0 ‰) compared to the $\delta^{18}O$ values of modern summer precipitation in the Qaidam Basin. As a result, the summer temperatures during the Early Eocene are estimated to be ~5 °C warmer than the present (Song et al., 2018a).

The Eocene-Oligocene transition is noted for a pronounced climatic cooling to icehouse conditions (Zachos et al., 2001; Ye et al., 2018). This climatic transition has been studied extensively from marine deposits, though relatively few studies have been attempted utilizing continental sources. Here, Ye et al. (2018) present a new study from the Qaidam Basin in the northeastern part of the Tibetan Plateau. They study the clay minerals, with a particular focus on chlorite, and identify a significant climatic change in the sediment record at 34.3 Ma that marks the Eocene-Oligocene transition. The change in chlorite composition indicates that the regional climate was drying out at that time (Ye et al., 2018). They further suggest that sediment from continental sources to some extent can provide robust evidence comparable to marine deposits.

The Tibetan Plateau uplift created many intracontinental basins, which are useful for deciphering the uplift history of the region. In this volume, Xu et al. (2018) report sedimentological, magnetostratigraphical, and paleogeographical investigations of the Neogene sedimentary basins in the northeastern part of the Tibetan Plateau. Angular unconformities and a sedimentary hiatus were widely observed in this region, suggesting a sustained uplift of the plateau between 23 and 17 Ma (Xu et al., 2018). The growing Qilian Shan during the Middle Miocene led to a cooler and drier climate on the western side but a humid and warm climate on the eastern side of the mountain. Grain size

https://doi.org/10.1016/j.palaeo.2018.11.003

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and sedimentation rates of deposits in the basins abruptly increased between 10-8 Ma, suggesting rapid uplift of the surrounding mountains and the rapid erosion of the Laji Shan. The basins gradually shrank and disappeared between 5.0-3.6 Ma due to the overall uplift of the Tibetan Plateau (Xu et al., 2018).

The Mid-Miocene Climatic Optimum (MMCO) is one of Earth's most recent prolonged warming events with temperatures ~6 °C warmer relative to the present day (Zachos et al., 2001), although atmospheric CO_2 levels were not high. The MMCO began with a warming trend but ended with the development of permanent ice sheets in Antarctica, which triggered the Mid-Miocene Climatic Cooling (MMCC) with a temperature decrease of > 5°C (Flower and Kennett, 1994; Holbourn et al., 2013). The thick Cenozoic deposits in the Longzhong Basin in northwestern China records clearly these Mid-Miocene climatic events. In this volume, Song et al. (2018b) examine the clay mineralogical and geochemical records of the Miocene red clay succession from the eastern Longzhong Basin. They find that the MMCO event occurred at 16–14 Ma. During the event, kaolinite and smectite contents, and illite crystallinity values are higher, while chlorite and illite contents are low. These characters of clay are consistent with the higher SiO_2/Al_2O_3 ratios and lower Al_2O_3 values in the sediments. Taken together, these ratios indicate greater precipitation and increased weathering, and thus, a warm and moist climate during the MMCO (Song et al., 2018b).

Understanding monsoon behavior is critical to developing strategies to combat its harmful impacts, particularly in monsoon regions where humans are densely populated. Climate modelers have been successful in understanding past climate change and projecting the future (e.g., Zhang et al., 2014; Yan et al., 2016). Here, Li et al. (2018a) analyze data from the Pliocene Model Intercomparison Project phase 1 to understand the impact of monsoons in different areas of the world during the mid-Pliocene. In general, the mid-Pliocene monsoon data indicate an increase in the monsoon area (7.3 %) and amount of precipitation (5.8 %) compared to preindustrial data. In the northern latitudes, the increase in monsoon area tended to move toward the pole. Li et al. (2018a) suggest these patterns to be related at least in part to an increase in atmospheric CO_2 and the retreat of major glaciation in the Northern Hemisphere during the mid-Pliocene.

Chemical weathering usually takes place under warm-wet conditions during interglacial periods (Sheldon and Tabor, 2009; Hong et al., 2010). However, for lacustrine and marine sediments, their weathering intensities were observed to respond to climate change differently in both temporal and spatial distribution (An et al., 2011; Zhao et al., 2017). Here, Sun et al. (2018) present a geochemical analysis of a sediment core drawn from Lake Xingkai that lies along the border between Heilongjiang Province in Northeast China and Siberia. The sediments are dated from the Last Glacial Maximum. They find that chemical analysis of the lacustrine sediments from Lake Xingkai was not a good proxy of changing climate across the glacial-interglacial transition. Similar Ti/Al and K/Al ratios between sediments from their core and loess-paleosol samples from northern China suggest that the sediment in Lake Xingkai during this depositional sequence may be of aeolian origin rather than from erosion of the rock catchment itself. Sun et al. (2018) hypothesize that a weak summer monsoon may have caused more fine grained particles to be aeolian transported to the region. Further studies should be conducted to test this hypothesis.

Chemical weathering will produce secondary minerals such as hydroxyl-bearing clays (e.g., kaolinite and smectite) and Fe-oxide minerals (e.g., hematite and goethite). As such, mineral and geochemical compositions are directly related to the environmental and climatic conditions that prevailed during pedogenesis (Clift et al., 2014; Mohanty et al., 2016). In more of a methodological approach to analyzing pedogenic weathering and ultimately paleoclimate change, Zhao et al. (2018) evaluate the potential utility of using visible-to-shortwave infrared reflectance spectroscopy to be able to predict to the same level of accuracy as more traditional geochemical and mineralogical techniques. Analyzing a sediment sequence from the Quaternary Shengli site in Sichuan Province, central China, Zhao et al. (2018) find that their results from infrared reflectance spectroscopy could be used to predict weathering intensity and molecular water and clay content. Their results suggest that infrared reflectance spectroscopy was most comparable to identify Fe-oxide mineralogy. It would be useful to see if this method is applicable across broader time and space units and hope to see future studies designed to further test this hypothesis.

3. Climate impact on regional paleoecology

Following the EECO, the Eocene-Oligocene transition witnessed one of the most abrupt cooling events during the Cenozoic (Zachos et al., 2001; Abels et al., 2011). With this event a number of major extinctions occurred among the various floras and faunas throughout the world. However, in certain places of the world, certain types of plants and animals were able to flourish and even diversify. Here, Dong et al. (2018) present a new species of *Burretiodendron* (*B. guangxiensis* sp. nov.) from Oligocene deposits in Guangxi Zhuang Autonomous Region in southern China. Although six extent species of *Burretiodendron* are present in Southeast Asia, fossil versions of this taxon were previously only known from neighboring Yunnan Province. This taxon is a good floral barometer for environmental variation because it is generally restricted to monsoon climates. *Burretiodendron* also flourishes in a karst environment, suggesting that its presence/absence can inform on the local temperature, moisture, and topography (Dong et al., 2018). As attested to this finding from Guangxi, it would suggest that the overall cooling that occurred during the Oligocene was not uniform across time and space.

As noted above, the MMCO was a peak in overall temperature between 16 Ma and 14 Ma (Zachos et al., 2001). In a study examining the impact of the MMCO on local plants, Hui et al. (2018) here contribute a detailed pollen analysis from profiles from the Longzhong Basin in the Tibetan Plateau. Using a Coexistence Approach, they find that, as with other studies, the overall temperature increased about 6 °C and precipitation was much higher than during the present day. A mixture of coniferous and broad-leaved forests was identified from the pollen analyses. This indicates that the climate was much wetter, warmer, and more seasonally balanced than today. Hui et al. (2018) postulate that the seasonality was weak because the height of the Tibetan Plateau may not have reached its present level yet or that the Plateau did reach its current level, but played a more minor role in impacting climate during the MMCO. Further, Hui et al. (2018) identified different precipitation gradients in north and eastern China during the MMCO, gradients that are similar to the present day, though with different intensities of annual precipitation.

During the Pleistocene, various hominin taxa (*Homo erectus*, mid-Pleistocene *Homo*, modern *H. sapiens*) appeared in China. The nature of the initial hominin appearance continues to receive growing attention in the scientific literature (Wolpoff et al., 1984; Wu and Wu, 1985; Pope, 1992; Wu and Poirier, 1995; Etler, 1996; Bae, 2010; Liu et al., 2014; Kaifu, 2017). What is of particular importance is the climate impacts on the timing, dispersal route(s), and occupation extent(s) of these various hominin populations. Evaluations of Pleistocene hominoid distributions in China have contributed to a better understanding of ecological variables that impacted hominin evolution in the region (e.g., Jablonski et al., 2000; Zhang and Harrison, 2017). Here, Bae et al. (2018) present up-to-date Pleistocene hominin occupation data in China. The data, presented over a series of topographical distribution maps (Early Pleistocene *H. erectus*, Middle Pleistocene *H. erectus*, Middle Pleistocene mid-Pleistocene *Homo*, early Late Pleistocene

modern *H. sapiens*, late Late Pleistocene modern *H. sapiens*), suggest that early hominins during the Early and early Middle Pleistocene were generally more restricted to central and southern China. Beginning in the latter part of the Middle Pleistocene, hominins begin to appear more regularly in northern China. In light of broad climatic fluctuations during the Pleistocene and the movement of the boundary between the Palearctic and Oriental biogeographic zones, this variation is perhaps understandable (Norton et al., 2010a). Bae et al. (2018) also raise a number of questions that could be testable hypotheses as the Chinese Pleistocene hominin fossil site occupation data becomes better understood in light of paleoclimate changes (e.g., hominin occupation variability between glacial and interglacial stages).

The origin of modern humans in eastern Asia continues to be a topic of great debate (Trinkaus, 2005; Norton and Jin, 2009; Bae et al., 2017a, 2017b). Given the limited support for traditional multiregional models of modern humans in the region (Wolpoff et al., 1984), the focus of most recent research has been on trying to better understand the when, where, and by which route did modern humans move out of Africa and arrive in eastern Asia (Bae et al., 2017a, 2017b). The evidence for early modern humans older than 50 ka in eastern Asia is growing, e.g., China: Zhiren Cave (Liu et al., 2010a); Luna Cave (Bae et al., 2014); Huanglong Cave (Liu et al., 2010b); and possibly Fuyan Cave (Liu et al., 2015; but see Michel et al., 2016) and Liujiang (Shen et al., 2002; but see Norton and Jin, 2009); Laos: Tam Pa Ling (Demeter et al., 2012); Sumatra: Lida Ajer (Westaway et al., 2017); Philippines: Callao Cave (Mijares et al., 2010). Here, Bacon et al. (2018) present a vertebrate paleontological and isotopic analysis of fossils from caves in the region (Nam Lot, Duoi U'Oi) near the important penecontemporaneous Tam Pa Ling site, to help contextualize the Late Pleistocene paleoenvironment during the time of human occupation in the region. According to the vertebrate paleontological analyses, these sites, dated to MIS 5 and 4, were dominated by large game weighing between 250 kg and 5,000 kg (e.g., *Tapirus indicus*, *Elephas* sp., *Stegodon orientalis*); a taxonomic composition completely different from the modern day. The isotope analysis indicated a strong C3 composition (closed forest), with only minor representation of C4 (open woodland) vegetation. The vertebrate paleontological and isotopic analyses both point in the same direction, regarding the paleoenvironment during MIS 5 and 4, in that the environment was occupied by a heavily tropical closed forest with a great deal of moisture, with only small pockets of more open woodland/grassland areas. As Bacon et al. (2018) note, the mosaic environment in the northern region of mainland Southeast Asia during MIS 5 and 4 would have been attractive for human foraging groups entering the region for the first time.

An interesting finding from the Bacon et al. (2018) study is that they observed that three extant species of rhinoceros (*Rhinoceros sondaicus*, *R. unicornis*, *Dicerorhinus sumatraensis*) were present in the Duoi U'Oi site that was dated to ~66 ka by multiple absolute dating methods. This suggests to Bacon et al. (2018) that the modern faunal composition in the region may have already been in place by MIS 4. This raises questions about how dependable vertebrate paleontology data are when trying to pinpoint a specific absolute time range for occupation of a site. A good example of this potential problem may be from Fuyan Cave in China where questions were raised about the reliability of the vertebrate paleontology to provide an absolute occupation time range (Michel et al., 2016).

The earliest peopling of the Japanese archipelago continues to be a point of great discussion among Japanese scientists and is a topic of growing international interest (Norton and Jin, 2009; Matsufuji, 2010; Norton et al., 2010b; Kaifu et al., 2015; Bae, 2017; Bae et al., 2017a, 2017b; Nakazawa, 2017). In particular, the timing and route of these early dispersals to the Japanese islands is heavily debated. In this issue, Nakazawa and Bae (2018) summarize the different hypotheses that have been proposed. One area they focus on closely is the impact of paleoenvironmental fluctuations (e.g., paleobathymetry) that may have created barriers or corridors to the archipelago from the Asian mainland in concert with the vertebrate paleontological and archaeological datasets. Although land corridors were likely present during MIS 16, 12, and 6, there is no evidence that hominins reached the archipelago during these glacial stages. Current data suggests that the earliest peopling of the Japanese archipelago was during the Late Pleistocene and likely some time during the latter part of MIS 3. In all likelihood, extenuating factors (e.g., increasing population pressure) on the Asian mainland may have prompted human foraging groups to seek out new horizons across large bodies of water where points of destination were in all likelihood not visible (Bae, 2017; Nakazawa, 2017; Nakazawa and Bae, 2018). More detailed reconstructions that link the paleoenvironment, vertebrate paleontology, and archaeology datasets is critical to developing a more refined understanding of how and when humans initially arrive in the archipelago and what happened once they did. The Nakazawa and Bae (2018) contribution adds to a growing number of studies that are more intensively exploring this topic.

The transition from the Neolithic to the Bronze Age in China around 4,200 yr BP is a heavily debated topic with explanations ranging from climatic factors to simply cultural changes (Liu and Feng, 2012; Wang, 2017). Here, Li et al. (2018b), analyzing the pollen from a core from the Late Neolithic Tianluoshan site in southeastern China, propose that the Neolithic to Bronze Age transition in China was likely due to a major period of climatic desiccation triggered by the El-Nino Southern Oscillation (ENSO). In particular, they noted that *Quercus* D appears to increase in the core suggestive of a transition from a subtropical forest type of environment to a more open evergreen and deciduous forest. The paucity or absence of *Altingia* in certain stratigraphic layers as well suggested a cooler environment (Li et al., 2018b). Although it is clear a major climatic event occurred around 4,200 yr BP, it should be remembered that major human behavioral transitions in prehistory (e.g., Paleolithic to Neolithic, Neolithic to Bronze Age, and Bronze Age to Iron Age) were almost surely not due to a single cause. For instance, in neighboring Korea, it has been proposed that increasing human population growth also needs to be accounted for in any explanation to describe the transition from the Neolithic to the Bronze Age in additional to environmental fluctuations and possibly the development of more complex societies (Norton, 2000, 2007; Bae et al., 2013).

4. Summary

What is clear from the two parts of this special issue focused on Cenozoic climate change in eastern Asia is that the regional paleoclimate is extremely dynamic. There are a growing number of research groups from various fields focused on geochemistry, clay mineralogy, sedimentology, climate modeling, paleontology, and palynology working in the region. The framework for paleoclimate variation can be better understood by including proxy data from terrestrial deposits in addition to what we have been learning from analyses of various marine sediments. Climate change during the Cenozoic clearly impacted the evolution of various floras and faunas in eastern Asia. The papers presented here help better understand the nature of this influence.

Acknowledgments

This special issue is partly supported by the Natural Science Foundation of China (41772032; 41472041), and the Fundamental Research Funds for the Central Universities, China University of

Geosciences (Wuhan) (No. CUG170106). We would like to thank Editor-In-Chief, Thomas Algeo, for the invitation to contribute this volume and for his great efforts in facilitating the editorial process. We thank Haeeun Shin for help with organizing the references. Any errors are solely the responsibility of the authors.

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